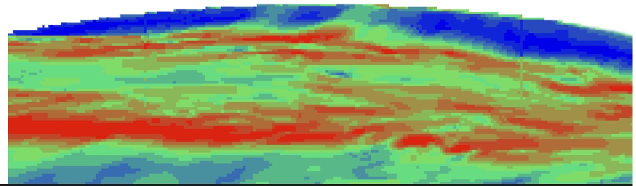

Reactor Core Hydrodynamics

Advanced simulations are paving the way to application of petascale computing for reactor thermal hydraulics analysis and design.

A new generation of sodium-cooled fast reactors is planned as a central element in the Global Nuclear Energy Partnership (www.gnep.energy.gov), which proposes to close the fuel cycle by transmuting and reusing spent fuel from thermal reactors in advanced recycling reactors. Among the benefits of GNEP would be an economically viable approach to significantly reduced loading (nearly 100-fold) in geological repositories. This INCITE project focuses on two fundamental design issues for the sodium coolant flow, namely, pressure loss (or required pumping power) and the degree of cross-assembly mixing induced by wire wrap spacers that separate fuel pins within each subassembly.

These questions are being addressed through large eddy simulations (LES) of turbulent flow in a sequence of subassembly geometries. Direct numerical simulation of this flow is infeasible because of the range of spatial and temporal scales at Reynolds number Re~50,000, the non-dimensional velocity characteristic of the coolant flow. Fortunately, important macroscopic features of the flow are accessible by simulating only the larger eddies in the flow field, which allows a significant reduction in the number of grid points and timesteps required to represent the numerical solution. Even so, the large number of coolant passages at design scales necessitates petascale computing resources for a full subassembly of 217 pins. Consequently, a systematic approach involving a sequence of pin counts (1, 7, 19, 37, etc.) is being undertaken, which allows one to identify and decouple the important effects of side and corner channels from the predominant interior channels. Interior channel effects are isolated by simulating a single pin in a periodic array.

2007 INCITE simulations have employed the 2,048-processor IBM Blue Gene/L at the Argonne Leadership Computing Facility. The computations are based on Nek5000, which simulates fluid flow, convective heat and species transport, and magneto-hydrodynamics in general 2-D and 3-D domains. Nek5000 has been developed at Argonne National Laboratory under the Department of Energy's Advanced Scientific Computing Research ASCR program. A singular feature is the code's ability to scale to the large processor counts that characterize petascale computing platforms, such as those soon to be deployed at Argonne and Oak Ridge National Laboratories. Several features of Nek5000 make it highly suitable for petascale science. The spectral element (SE) method, on which the code is based, yields rapid numerical convergence, which implies that transport of small scale features over long times and distances incur minimal numerical dissipation and dispersion. In effect, accuracy per gridpoint is maximized. The code also features scalable multigrid methods capable of solving systems with 10^8 degrees of freedom in only 10-50 iterations.

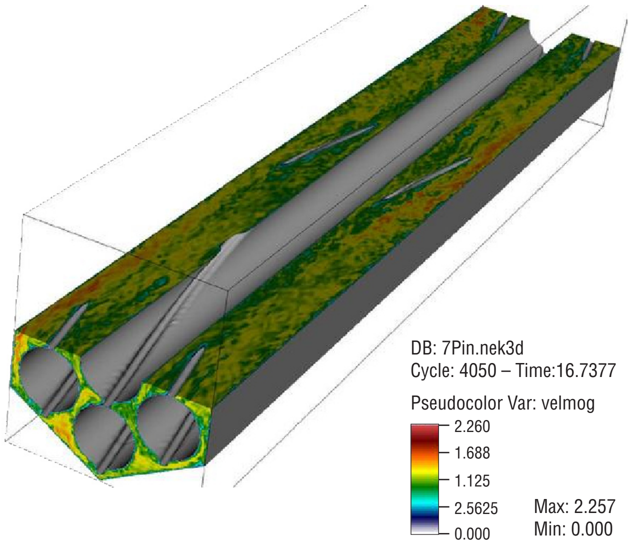

Figure 1. Turbulent velocity field in a 7-pin bundle with wire-wrap spacers.

2007 INCITE computations have focused on a single pin in a periodic array and on the 7-pin case, which is the smallest configuration that features all three subchannel types. Figure 1 shows a cutaway view of the turbulent velocity field in a 7-pin configuration. The computational mesh of ~44 M gridpoints uses 132,000 elements of order N=7 (512 points per element).

The single- and 7-pin simulations have been able to identify cross-flow velocities between coolant subchannels. These distributions are one of the key results from experiments and, now, simulations because they characterize the essential aspects of the velocity fields for subsequent design scoping studies. While the single-pin results exhibit a nearly sinusoidal cross-flow distribution as a function of axial position, the 7-pin results show markedly different behavior. The interior distributions (A-A and B-B in Figure 2) have higher wavenumber content and lower amplitude than the single-pin case. The exterior interfaces (C-C and D-D) have nonzero means, which indicates a net swirling flow around the subassembly, as reported in previous experiments.

In addition to the results shown, researchers have quantified the effects of varying wire-wrap pitch for the single pin case and are now studying the same question for 7 pins. 19- and 37-pin configurations will be studied in 2008.

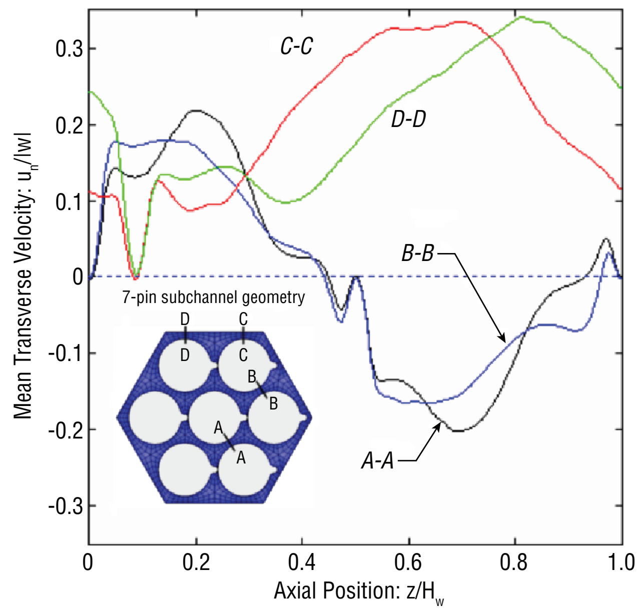

Figure 2. 7-pin cross flow distributions.

The Argonne Leadership Computing Facility and the INCITE program directly support ASCR's primary mission to discover, develop, and deploy computational and networking tools that enable researchers in the scientific disciplines to analyze, model, simulate, and predict complex phenomena.

Contributors:

Paul Fischer
Argonne National Laboratory

Andrew Siegel
Argonne National Laboratory

Carlos Pantano
University of Illinois

For more information on this subject, please contact:

Dr. Paul Fischer
Mathematics and Computer Science
Argonne National Laboratory
630-252-6018
fischer@mcs.anl.gov

For more information about ALCF, please contact:

Pete Beckman, Acting Division Director
Argonne Leadership Computing Facility
Argonne National Laboratory
630-252-9020
beckman@mcs.anl.gov

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